

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
4 April 2002 (04.04.2002)

PCT

(10) International Publication Number  
**WO 02/26134 A1**

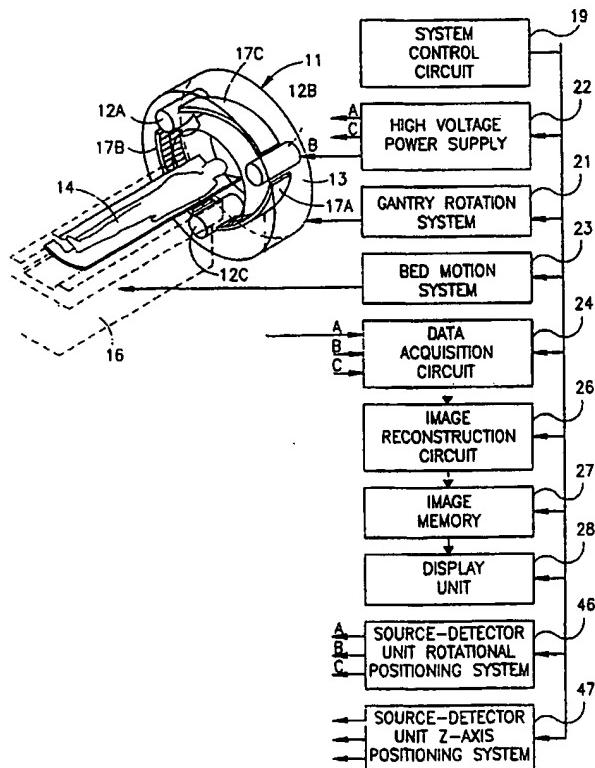
- (51) International Patent Classification<sup>7</sup>: **A61B 6/03**
- (21) International Application Number: **PCT/IL00/00610**
- (22) International Filing Date:  
28 September 2000 (28.09.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (71) Applicant (*for all designated States except US*): **MARCONI MEDICAL SYSTEMS ISRAEL, LTD. [IL/IL]**; P.O. Box 325, 31004 Haifa (IL).
- (72) Inventor; and
- (75) Inventor/Applicant (*for US only*): **MALAMUD, Gabriel [IL/IL]**; Ha'einav Street 5, 30500 Benyamina (IL).
- (74) Agents: **FENSTER, Paul et al.; Fenster and Company Patent Attorneys, LTD., P.O. Box 10256, 49002 Petach Tikva (IL).**
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EB, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

*[Continued on next page]*

(54) Title: CT SCANNER FOR TIME-COHERENT LARGE COVERAGE



**WO 02/26134 A1**



(57) Abstract: In a rotate CT scanner a plurality of source-detector units are mounted on a gantry displaced from each other in the Z direction and the detector units are arranged to acquire data from large volumes of a subject in a single rotation so that the scanner can provide time-coherent images of large organs.



**Published:**

— *with international search report*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**CT SCANNER FOR TIME-COHERENT LARGE COVERAGE****FIELD OF THE INVENTION**

This invention is concerned with computerized tomographic (CT) systems, and more particularly with such systems equipped with multiple sources of radiation mounted for 5 rotation around the patient at different locations along the longitudinal axis of the patient or object, and further wherein the X-ray beams from each of the sources encompass multiple rows of detectors.

**BACKGROUND OF THE INVENTION**

The first CT scanners used sources transmitting X-rays with pencil beams and 10 oppositely disposed single detectors which were moved laterally and then rotationally relative to the object. The CT scanners evolved into using X-ray sources transmitting rotatable fan beams along with an oppositely disposed rotatable detector array. In those first rotate-rotate CT scanners, a single row of detectors was used in the detector array. The fan beam angle was sufficiently large so that the fan beam encompassed the single row of detectors. The length of 15 the detectors along the patient or object axis (the Z axis) defined the maximum slice width that could be covered in a "single-shot" without the scanned object or the scanning frame (hereafter referred to as a "scanning unit") being moved during the scan. In the early '90s, a dual slice machine was introduced in which the oppositely disposed detector array, comprised at least two rows of detectors. This increased the coverage in the Z direction. See, for example, U.S. 20 Patent 5,228,069, the contents of which are incorporated herein by reference and made a part hereof.

Another improvement in the scanners was the use of multiple focal spots in the X-ray source, which substantially increased the resolution of the acquired images. See, for example, U.S. Patent 4,637,040, the contents of which are incorporated herein by reference and made a 25 part hereof. Subsequently, multiple X-ray sources at the same Z location were used with detector arrays capable of detecting X-rays from more than one slice. Thus, the detectors were arrays of multiple rows of detectors, so that in a single revolution data for multiple slices were acquired. See, for example, U.S. Patent 5,966,422, the contents of which are incorporated herein by reference and made a part hereof. A further improvement was the provision of 30 helical scans. See, for example, U.S. Patent Application Serial No. 08/556,824 and French Patent 9209141, the contents of each of which are hereby incorporated herein by reference.

**BRIEF DESCRIPTION OF THE INVENTION**

However, until the present invention, there has been no known CT scanner that combines multiple X-ray sources and associated detector array units wherein the units are

displaced relative to each other along the Z axis, and wherein each of the arrangements are capable of acquiring multiple slice data.

- Besides other advantages, some embodiments that use multiple source detector array arrangements displaced along the Z axis in combination with detector arrays that comprise
- 5 multiple rows of detectors or large area detectors can provide one or more of the following: large area coverage, high quality time-coherent CT scans, minimize potential cone-beam artifacts, decreases the technical complexities involved in fast data extraction, which are needed for simultaneous imaging of high-resolution volumes of interest (VOI) in the scanned objects. Such combinations of X-ray sources and detector array combinations can provide
- 10 high-resolution images of complete, large organs such as, for example, the heart in a time-coherent "single shot" image without the need to move the patient or the scanning frame, in order to scan different regions of the volume of interest. This enables a simultaneous scan, or a true cine scan via either "continuous-dynamic" or "gated" axial scans. In cases where a coverage larger than the basic single shot is needed, either a series of axials, or a contiguous
- 15 helix scan can be done, still accelerating the speed and improving the quality of a single-source system, with a single detector array, having the same or a smaller coverage.

According to an aspect of some embodiments disclosed herein, there is provided a plurality of radiation sources, each source operating with a detector array to form a scanning unit wherein the scanning units are shifted with respect to each other along the longitudinal 20 axis of the object. Optionally, either the distance between arrays or cooperating baffles are designed so that each of the fan beams covers a different object plane or volume. Object planes or volumes may be contiguous.

- In accordance with some embodiments of the present invention, a unique CT scanner system is provided. The system comprises a plurality of X-ray sources mounted around the 25 patient at different Z (axial) locations with detector arrays displaced opposite to each of the sources at the different Z locations. Each of the X-ray beams encompasses multiple rows or large area arrays of detectors to form scanning units, so that a rotation around the scanned object (patient or any other object) may provide simultaneous multi-slice image data. In this manner, the scanning units, i.e., the multiple X-ray sources and oppositely disposed large area 30 detectors or multiple rows of detectors, enable time-coherent coverage of a large volume of an object. Such coverage has never before been accomplished. Thus, time-coherent multiple slice or large volume coverage by the detector arrays can be made in a single rotation of the unique CT scanning units, i.e., the multiple sources combine with individual oppositely disposed

unique detector array arrangements capable of being displaced from each other in the Z direction.

There is thus provided, in accordance with an embodiment of the present invention, a CT system is provided; the CT system includes a plurality of X-ray sources mounted on a gantry for rotation about an object, said X-ray sources being located at different axial locations, X-ray detector arrays mounted on said gantry individually associated with and situated opposite to each of said X-ray sources at the different axial locations and each of said detector arrays having multiple rows of detectors in the axial direction, said multiple rows of detectors traversing a plurality of slices of the object at said different axial locations during a single rotation.

In some embodiments of the present invention, said plurality of slices encompass a substantial length of an organ in said object. Also in accordance with the above mentioned aspects, the said plurality of slices may encompass at least the entire length of an organ in said object.

The organ may be, for example a human heart.

In accordance with another aspect of the present invention, the detector arrays comprise multiple rows of individual detectors.

In accordance with some embodiments of the present invention, said detector arrays comprise area detectors. The detectors may be sufficiently large to encompass at least the entire length of an organ in said object, or area detectors that are sufficiently large to encompass a substantial length of an organ in the object.

Optionally, at least one of the said X-ray sources utilizes multiple focal spots.

In some embodiments, said X-ray sources with said associated detector arrays and said object move relative to each other in the Z direction to provide a helical scan. Alternatively, said X-ray sources with said associated detector arrays and said object are moved relative to each other in the Z direction to provide a set of n axial scans where  $n \geq 1$ .

According to an aspect of some embodiments of the present invention, the plurality of sources are rotationally removed from each other by any angle  $\theta$  where  $0^\circ \leq \theta \leq 180^\circ$ .

In an embodiment of the invention, the X-ray sources emit fan beams of X-ray radiation; and the fan beams of at least two of the X-ray sources traverse overlapping sections of the object in the axial direction. Alternatively, the fan beams of at least two of the sources are contiguous to each other in the axial direction. In yet another alternative arrangement, the fan beams of at least two of the sources that illuminate the object are spatially separated in the axial direction. Alternatively, the X-ray beams are cone beams.

According to some embodiments of the present invention, the X-ray detectors are arranged to provide time-coherent multiple slices of the object. Alternatively, the X-ray detector arrays are arranged to provide time-coherent large area views of the patient.

There is further provided, in accordance with an embodiment of the invention a CT system including: a plurality of X-ray sources mounted on a gantry for rotation about an object, a plurality of X-ray detector arrays mounted on said gantry, each being individually associated with and situated opposite to each of the X-ray sources to form a plurality of source-detector units and a source detector unit positioning system for selectively positioning said units at the same axial position or at different axial positions during a single rotation.

There is further provided, in accordance with an embodiment of the invention an imaging method including: mounting a plurality of X-ray sources on a gantry, rotating said gantry around a patient, locating said X-ray sources at said different Z locations, mounting a plurality of detector arrays on said gantry individually associated with and displaced opposite to each of the X-ray sources at different Z locations and simultaneously detecting X-rays that have traversed a plurality of sections of the patient at said different Z locations during a single rotation with said detector arrays.

In accordance with an embodiment of the present invention, said plurality of sections of the patient encompass a substantial length of a human organ, or said plurality of sections of the patient encompass at least the entire length of a human organ and said human organ is an adult heart.

In accordance with an embodiment of the present invention, the detector arrays comprise multiple rows of detectors, where the detectors are individual detectors. Alternatively, the detector arrays comprise wide-area detectors.

According to an embodiment of the present invention, at least one of said X-ray sources utilizes multiple focal spots.

Optionally, a helical scan is provided by moving said X-ray sources with said associated detector arrays and said patient relative to each other in the axial direction.

Alternatively or additionally, moving the X-ray sources with said associated detector arrays and said object relative to each other in the axial direction to provide a set of n axial scans where  $n \geq 1$ .

Optionally, the plurality of sources are rotationally removed from each other by any angle  $\theta$  where  $0^0 \leq \theta \leq 180^0$ . Optionally, the X-ray sources emit fan beams of X-ray radiation and the fan beams of at least two of the X-ray sources traverse overlapping sections of the patient in the axial direction. Alternatively, the fan beams of at least two of the X-ray sources

are contiguous to each other in the axial direction. According to still another alternative, the fan beams of at least two of the sources are spatially separated in the axial direction. The fan beams may be cone beams.

5 An embodiment of the invention includes arranging the X-ray detectors arrays to provide time-coherent multiple slices of the patient. Alternatively, the X-ray detector arrays are arranged to provide time-coherent large area views of the patient.

There is further provided, in accordance with an embodiment of the invention, a CT imaging method is provided that includes mounting a plurality of X-ray sources on a gantry, mounting a plurality of detector arrays on said gantry, each of said detector arrays being 10 individually associated with each of said X-ray sources, and being placed opposite to said sources to form a plurality of source-detector units and selectively locating said units at the same axial location for detecting X-rays that have traversed the same section of a patient during the single rotation during a single rotation or locating said units at different axial locations for simultaneously detecting X-rays that have traversed a plurality of sections of the 15 patient at said different axial locations during a single rotation.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting embodiments of the present invention are described below with reference to figures attached hereto. In the figures, identical structures, elements or parts that appear in more than one figure are generally labeled with the same numeral in all figures in which they 20 appear. Dimensions of components and features shown in the figures are chosen for convenience and clarity of presentation, and not necessarily shown to scale. The figures are listed below.

Fig 1A is a combination pictorial and block diagram showing an example of a prior art CT scanner using multiple sources in conjunction with detector arrays having multiple rows of 25 detectors;

Fig. 1B is a showing of a typical system of coordinates defined by a CT scanning system;

Fig. 2 is a simplified side elevation view illustrating the configuration wherein a plurality of multiple slice images are simultaneously generated according to an embodiment of 30 the present invention;

Fig. 3 is an illustration showing the maximum coverage for which cone beam artifacts can be neglected or are tolerable;

Fig. 4 shows a two source, two array detection system according to an embodiment of the present invention wherein the two sources are shown as being  $180^0$  apart on the rotation frame and displaced from each other in the Z direction;

Fig. 5 is a three dimensional illustration of a combined multiple source, multiple detector array scanner wherein the source and combined detectors are rotated to be separated by angles different than  $180^0$  and are displaced from each other in the Z direction according to an embodiment of the invention;

Fig. 6 is a schematic illustration of a group of a four focal spot source and detector units where Z displacement between the combined adjacent source and detector units is defined by  $\Delta Z = C_{max}$  and the angular displacement is shown as  $180^0$ ; according to an embodiment of the invention; and

Fig. 7 is a combination pictorial and block diagram showing of a CT scanner according to an embodiment of the invention including CT scanning units, each comprising an X-ray source operating with an oppositely disposed detector array, each unit capable of being positioned separately at different rotational and/or longitudinal locations along the Z axis.

#### GENERAL DESCRIPTION

Fig. 1A is a general layout of a third generation (rotate-rotate) scanner 11 comprising three X-ray sources 12A, 12B and 12C, mounted on a gantry 13. A subject or patient 14 to be scanned is shown being supported by means of the bed 16. Fan-shaped X-rays, which traverse a planar section through the subject 14 are detected by a plurality of detector arrays shown by way of example as detector arrays 17A, 17B and 17C.

Cartesian coordinate system 18 is shown in Fig. 1B. Therein a common Z axis is defined as being along the longitudinal axis of rotation of the gantry. The Z axis defines a longitudinal axis through the subject. A Y axis is defined as being along a straight line from each of the X-ray sources to the center of revolution of the gantry 13 and the X axes are perpendicular to the above axes. As gantry 13 rotates about the Z axis so do coordinate systems 18 rotate about the Z axis.

According to the prior art showing of Fig. 1A, there are three X-ray sources 12A, 12B and 12C and oppositely disposed detector arrays denoted as 17A, 17B and 17C. However, according to the invention described herein, the number of combined source and detector arrays may be different than three.

Detector arrays 17 detect the X-rays that pass through planar sections in subject 14. The apparatus illustrated in Fig. 1A is referred to as a multiple source, multiple slice CT scanner of the third generation type.

The various operations of the computerized tomography system 11 are controlled by means such as a system control circuit 19. More particularly, circuit 19 controls, among other things, the operation of a gantry rotation system 21. Thus, the prior art gantry 13 with X-ray sources 12A, 12B and 12C revolves about the Z axis, powered and controlled by gantry rotation system 21. The X-ray sources 12A, 12B and 12C are energized by a high-voltage power supply 22, as they rotate around the subject 14. The subject 14 is positioned within a central aperture of gantry 13 by means of a bed motion system 23, which controls the movement of a bed 16.

The maximum coherent coverage of the system is defined by the coverage of each detection array, and by the number of X-ray sources and detection systems. Note that the coverage of the various arrays may differ. Also, at some times and upon clinical needs, only part of the available X-ray sources may be actively irradiating the patient.

The intensity of radiation after its traversal of the patient 14 is detected by detector arrays 17 and acquired by a data acquisition circuit 24. Radiation intensity data from the rays traversing the patient 14 over a range of at least 180° in the gantry revolution plane are used to reconstruct an image by means of image reconstruction circuitry 26, in conjunction with an image memory 27. The reconstructed image is displayed on a display unit 28.

Variations of the system of Fig. 1A are known in the art, and the device of Fig. 1A is useful for illustrative purposes. However, it should be understood that Fig. 1A is not limiting to the invention, which is applicable to a wide variety of CT systems, as known in the art.

In the past, as well as according to the present invention, simultaneously with gantry 13 rotation about the Z axis, subject 14 may be moved by means of bed 16 under the control of bed motion system 23. The bed may also be capable of being moved at oblique angles to the gantry 13 revolution plane i.e., the X, Y plane. Furthermore, in the embodiment of prior art, as well as the present invention, the rotating portions of gantry 13 may revolve continuously for more than one revolution, as is possible with slip-ring construction. The gantries in the prior art, as well as the present gantry, can therefore perform helical scans. However, note that even with helical scans in the prior art, time-coherent, wide-angle coverage of a large organ such as the heart is not possible. In the prior art, each revolution takes a slice that is a smaller portion of the organ. The slices are not acquired at the same time thereby precluding time-coherent coverage of the organ.

Fig. 2 shows the three X-ray sources 12A, 12B and 12C displaced along the Z direction, in accordance with an embodiment of the invention. For the sake of simplicity, the sources are shown at the same angular location; although, according to the various embodiments of the present invention the multiple sources may have different angular displacements. The X-ray source 12B is shown with solid lines, while sources 12A and 12C are shown in dotted line form to emphasize that they preferably are actually disposed at different angular positions about the axis of rotation. Note that an optional radial opaque baffle 31 is shown disposed between X-ray sources 12 and X-ray detectors shown indicated generally at 17A, 17B and 17C. The baffle, which is useful when the X-ray source-detector units are at different angles such that the beam angles do not overlap, may rotate in front of each of the detector arrays to block scatter from adjacent slices. The baffle 31 is designed to pass a desired X-ray fan beam. With the X-ray source and detector units at different angular positions a baffle screen may be provided for each source-detector arrangement. Accordingly, in any instant, each of the detectors is in the fan beam of only its associated X-ray source. When the units are at the same angular position, they are spaced apart in the longitudinal direction to assure that the X-ray beams do not overlap.

Any wobble that occurs in the multiple contiguous slice configurations is correctable by providing X-ray detectors which are active along a sufficiently long axial dimension. Then, when the X-ray fan beam sources are operated even under conditions of wobble in the planar mode, all of the wobbly X-ray fan beams still impinge upon an active element of the detector array. In Fig. 2 the axis of rotation is shown at dot dash line 32, while the solid lines 13 are the contours of the patient and/or the X-ray tunnel.

The arrangement using multiple X-ray sources displaced along the Z axis and associated multiple detector or wide-area detector arrays enables large, high-resolution, time-coherent coverage of the scanned object, either free of or with minimal cone beam artifacts even without helix operation. With helix operation, the disclosed arrangement will enable faster helix coverage of objects with large volumes with actual real time coherence. The system is based on using, in the same rotating frame of reference, a group of  $n(>1)$  X-ray sources and associated detection array units that are displaced along the Z axis with a distance between them sufficient to minimize cone beam artifacts. The coverage and displacement of these scanning units is calculated so that a contiguous combined coverage is preferably achieved while each of these units is free of cone beam artifacts. The coverage of each of the scanning units is designed so that the angular Z coverage is within an acceptable cone beam level. That is, with minimum cone beam artifacts.

Note that cone beam artifacts are function of both actual cone aperture and of the cone beam correction level via proper reconstruction algorithms. Therefore, the "free-of-cone beams artifacts" coverage definition is a "free" parameter which depend(s) on the specific algorithm and the specific clinical needs.

5 Fig. 3 is an illustration of a scanning unit 35 comprising a single source 30, and a detector array 33, in accordance with an embodiment of the invention. In Fig. 3  $C_{max}$  is the maximum coverage in the object plane for which cone beam artifacts as a function of the overall system geometry are tolerable. An angle  $\alpha_{max}$  is a corresponding angular coverage in the Y Z plane. The number of detectors in the Z direction and hence the number of slices per  
10 scan is shown in Fig. 3 as thirteen. Such a showing is arbitrary and only by way of example. Thus, a different number of detectors can be used within the scope of the present invention. In Fig. 3 the object plane is at 32. The number 34 indicates that Fig. 3 is in the Y Z plane, Z being along the axis of rotation, and Y being the direction between source 31 and detectors 32. Detector array 33, as mentioned before, is shown as having thirteen individual detectors, such  
15 as detector 33A. The thirteen individual detectors are used to define individual slices during the scanning and acquisition process.

Fig. 4 shows a group 40 of two scanning units, in accordance with an embodiment of the invention, wherein the individual scanning units are displaced from each other along the Z axis. In addition, in Fig. 4 the individual scanning units have an angular displacement between  
20 the radiation sources of  $180^0$ . It should be recognized that, within the scope of the invention, the angular displacement of individual scanning units can be different from  $180^0$ . In Fig. 4 there is shown a source 36A working in conjunction with a detector array 37A. As shown in Fig. 4, at an angle of  $180^0$  from source 36A is a source 36B, which operates in conjunction with a detector array 37B. Here again, the source detector combinations are shown by way of  
25 example as being in the Y Z plane, indicated at 41. The object plane is shown as  $C_{max}$ . Thus, the coverage during rotation of the system is  $2C_{max}$ . The angle  $\alpha_{max}$  defines the width of the X-ray fan beam that may be used without creating intolerable cone beam artifacts.

While any angular displacement of the sources from one another can be used, if the angular displacement is smaller than the fan beam in the X Y plane, and if the Z displacement is smaller than array width, the two beams, while irradiating the object simultaneously from the two sources will be partially overlapping on the detector planes, which will prevent proper separated read-out of the signal. In practical terms, then, the displacement of the source  
30

detector array scanning units from each other, in both the X and Z directions, is generally at least one fan beam angle  $\alpha$ .

Fig. 5 is an exemplary three-dimensional illustration of an inventive multiple source multiple row detector scanner, in accordance with an embodiment of the invention. In this example the sources are separated by an angle different than  $180^0$ . More particularly, in Fig. 5 there is shown a source 12A which illuminates a detector array at 17A. A second source 12B illuminates a detector array 17B. In the detector arrays, the rows of detectors extend in the Z direction. The arrays also extend in the rotational direction. The fan beam is shown as extending in the Z direction over an angle  $\alpha_{max}$ . The rotational distance between source 12A and 12B is different than  $180^0$ . Fig. 5 illustrates and emphasizes that it is not required that the sources be separated from each other by  $180^0$ , or even be separated by equal divisions of  $360^0$ . Thus, it is not necessary when there are two source detector array units that they be separated by  $180^0$ , or when there are three source detector array units that they be separated by  $120^0$ .

Fig. 6 is a showing of a group of four X-ray source detector array units. The angular displacement therein between adjacent CT scanning units is shown as being  $180^0$ . The  $\Delta Z$  displacement is defined by the conical fan beam  $\alpha$  which illuminates the object plane. The Z coverage of the four CT scanning units is  $4C_{max}$  at the object plane. The Z spacing between the CT scanning units is not restricted to the  $C_{max}$  distance, but is rather a subject for optimization. Within the scope of the invention, coverage of an "object plane" may use a somewhat smaller displacement that provides less than contiguous coverage, or may use a bigger displacement to obtain contiguous coverage, or may use a still bigger displacement to obtain simultaneous coverage. The coverage in an embodiment of the invention is ideally equal to or a substantial part of the longitudinal length of an adult heart i.e., 10-15 cm.

In Fig. 6, four CT scanning units are shown. They are comprised of sources 12A, 12B, 12C and 12D. Each source is individually associated with oppositely disposed detector arrays such as detector array 17A, 17B, 17C and 17D, respectively. It should be noted that the sources could be dual focus spot X-ray sources. With the embodiment shown in Fig. 6, twice as much coverage may be obtained as in the embodiment of Fig. 4. Here again, the Y and Z axes are shown at 34.

Fig. 7 is a block diagram illustration of an embodiment of the invention showing some features not in the prior art. In Fig. 7 three CT scanning units are shown. They are shown

positioned with all of the CT scanning units in the same Z locations i.e., in the same plane; which is one option. However, according to Fig. 7, there is also included a rotational positioning system 46 for individually varying the angular displacement rotation of each of the CT scanning units, comprising sources 12 and oppositely disposed individually associated detector arrays 17. The rotational positioning system is operational when the units are at different longitudinal positions. Block 47 shows a system for individually positioning each of the source detector units along the Z axis, either in the same plane or in different frames or in combinations thereof.

Thus, according to the system disclosed in Fig. 7, all of the individual CT scanning units can be positioned at the same Z axis location to operate as in the prior art, or they can each individually be positioned along the Z axis, at a different Z axis location, in accordance with the system explained with regard to Fig. 4, for example. Thus, the disclosed system provides versatile scanning arrangements including prior art features and new features.

The Z displacement of the CT scanning units can be fixed or variable. Also, the rotational displacement of the combined source-detector units can be fixed or variable. Thus, within the scope of the invention, as shown in Fig. 7, the scanning apparatus incorporates a capability to change the Z position of each combined source detector unit; that is, each source-detector unit can be independently moved in the Z direction. The system of Fig. 7 selectively combines the advantages of gantries having multiple sources and detectors in a single plane and multiple sources and detector units, each in a different plane. When the source detector units are in different planes, it is advisable to use all source detector units in the different planes simultaneously. However, certain time lags between scan frames may be introduced in order to achieve certain time dependencies or to stay within power supply limits, or in order to reduce the scatter radiation which crosses between detection frames.

The systems presented enable the acquisition of relatively large coverage, time-coherent images without the need for helical motion. However, the scanners described herein, of course, can be utilized in the helical mode while providing the large coverage for very high-scan speeds. It is in such cases that the variable Z spacing between the different source detection frames is a useful adaptation, since it allows for matching the spacing to the helix angle. It is also possible in the system for certain scans to use only some of the source detection systems, while others are not used. Similarly, the X-ray sources can be energized simultaneously or during separated time slots in order to effectively provide multi-energy modalities.

A person skilled in the art of X-ray detection will appreciate that the present invention is not limited to a particular detector array or to particular X-ray sources, but rather to any apparatus that deals with the intensity and position of the X-rays. In particular, detector arrays, such as detector arrays 17A-17D may comprise multiple-detector elements, multiple-segmented detector elements in an array of single detectors or continuous wide-area media responsive to X-rays that also provides position read-outs.

As used herein, the terms "comprise", "include" or "have" or their conjugates mean "including but not necessarily limited to."

Although the invention has been described with reference with particular embodiments, the invention is not confined to the specific embodiments described herein and above, but rather to the general scope of the claims attached hereto.

WHAT IS CLAIMED IS:

1. A CT system including:
  - a plurality of X-ray sources mounted on a gantry for rotation about an object, said X-ray sources being located at different axial locations;
  - X-ray detector arrays mounted on said gantry individually associated with and situated opposite to each of said X-ray sources at the different axial locations; and
  - each of said detector arrays having multiple rows of detectors in the axial direction, said multiple rows of detectors traversing a plurality of slices of the object at said different axial locations during a single rotation.
2. The CT system of claim 1 wherein said plurality of slices encompasses a substantial length of an organ in said object.
- 15 3. The CT system of claims 1 or 2 wherein said plurality of slices encompasses at least the entire length of an organ in said object.
4. The CT system of claims 2 or 3 wherein said organ is a human heart.
- 20 5. The CT system of claims 1-4 wherein said detector arrays comprise multiple rows of individual detectors.
6. The CT system of any of claims 1-4 wherein said detector arrays comprise area detectors.
- 25 7. The CT system of claim 6 wherein said area detectors are sufficiently large to encompass at least the entire length of an organ in said object.
8. The CT system of claim 6 wherein said area detectors are sufficiently large to encompass a substantial length of an organ in the object.
- 30 9. The CT system of any of claims 1-8 wherein at least one of the said X-ray sources utilizes multiple focal spots.

10. The CT system of any of claims 1-9 wherein said X-ray sources with said associated detector arrays and said object move relative to each other in the Z direction to provide a helical scan.

5

11. The CT system of any of claims 1-9 wherein said X-ray sources with said associated detector arrays and said object are moved relative to each other in the Z direction to provide a set of  $n$  axial scans where  $n \geq 1$ .

10 12. The CT system of any of any of the previous claims wherein said plurality of sources are rotationally removed from each other by any angle  $\theta$  where  $0^0 \leq \theta \leq 180^0$ .

13. The CT system of any of the previous claims wherein said X-ray sources emit fan beams of X-ray radiation; and

15 wherein the fan beams of at least two of the X-ray sources traverse overlapping sections of the object in the axial direction.

14. The CT system of any of claims 1-12 wherein said X-ray sources emit fan beams of X-ray radiation and wherein the fan beams of at least two of the sources are contiguous to each 20 other in the axial direction.

15. The CT system of any of the previous claims wherein said X-ray sources emit fan beams of X-ray radiation; and

25 wherein the fan beams of at least two of the sources that illuminate the object are spatially separated in the axial direction.

16. The CT system of any of the claims 13-15 wherein the fan beams are cone beams.

17. A CT system including:

30 a plurality of X-ray sources mounted on a gantry;  
a plurality of detector arrays mounted on said gantry;  
said detector array being mounted opposite to and being individually associated with one of said plurality of X-ray sources at different axial locations; and

said X-ray detectors are arranged to provide time-coherent multiple slices of the object.

18. The CT system of claim 17 where the X-ray detector arrays are arranged to provide time-coherent large area views of the patient.

5

19. A CT system including:

a plurality of X-ray sources mounted on a gantry for rotation about an object;

a plurality of X-ray detector arrays mounted on said gantry, each being individually associated with and situated opposite to each of the X-ray sources to form a plurality of source detector units; and

10 a source detector unit positioning system for selectively positioning said units at the same axial position or at different axial positions.

20. A CT scanning method including:

15 mounting a plurality of X-ray sources on a gantry;

rotating said gantry around a patient;

locating said X-ray sources at different Z locations;

mounting a plurality of detector arrays on said gantry individually associated with and displaced opposite to each of the X-ray sources at different Z locations; and

20 simultaneously detecting X-rays that have traversed a plurality of sections of the patient at said different Z locations during a single rotation with said detector arrays.

21. The CT scanning method of claim 20 wherein said plurality of sections of the patient encompass a substantial length of a human organ.

25

22. The CT scanning method of claim 20 wherein said plurality of sections of the patient encompass at least the entire length of a human organ.

23. The CT scanning method of claims 21 or 22 wherein said human organ is an adult heart.

- 30 24. The CT scanning method of any of claims 20-23 wherein said detector arrays comprise multiple rows of detectors.

25. The CT scanning method of any of claims 20-24 wherein said detector arrays comprise multiple rows of individual detectors.
- 5 26. The CT scanning method of any of claims 20-25 wherein said detector arrays comprise wide-area detectors.
27. The CT scanning method of any of claims 20-26 wherein at least one of said X-ray sources utilizes multiple focal spots.
- 10 28. The CT scanning method of claims 20-27 and providing a helical scan by moving said X-ray sources with said associated detector arrays and said patient relative to each other in the axial direction.
- 15 29. The CT scanning method of any of the claims 22-28 including moving said X-ray sources with said associated detector arrays and said object relative to each other in the axial direction to provide a set of  $n$  axial scans where  $n \geq 1$ .
30. The CT scanning method of any of claims 20-29 wherein said plurality of sources are 20 rotationally removed from each other by any angle  $\theta$  where  $0^\circ \leq \theta \leq 180^\circ$ .
31. The CT scanning method of any of claims 20-30 wherein:  
said X-ray sources emit fan beams of X-ray radiation; and  
the fan beams of at least two of the X-ray sources traverse overlapping sections of the 25 patient in the axial direction.
32. The CT scanning method of any of claims 20-30 wherein:  
said X-ray sources emit fan beams of X-ray radiation; and  
the fan beams of at least two of the X-ray sources are contiguous to each other in the 30 axial direction.
33. The CT scanning method of any of claims 20-30 wherein:  
said X-ray sources emit fan beams of X-ray radiation; and

the fan beams of at least two of the sources are spatially separated in the axial direction.

34. The CT scanning method of any of claims 31-33 wherein the fan beams are cone beams.
35. The CT scanning method of any of claims 20-34 wherein the X-ray detector arrays are arranged to provide time-coherent multiple slices of the patient.
- 10 36. The CT scanning method of any of claims 20-35 wherein the X-ray detector arrays are arranged to provide time-coherent large area views of the patient.
- 15 37. A CT imaging method including:
  - mounting a plurality of X-ray sources on a gantry;
  - mounting a plurality of detector arrays on said gantry, each of said detector arrays being individually associated with each of said X-ray sources, and being displaced opposite to said sources to form a plurality of source detector units; and
  - selectively locating said units at the same axial location for detecting X-rays that have traversed the same section of a patient during a single rotation or locating said units at different axial locations for simultaneously detecting X-rays that have traversed a plurality of sections of the patient at said different axial locations during a single rotation.
- 20

1/5

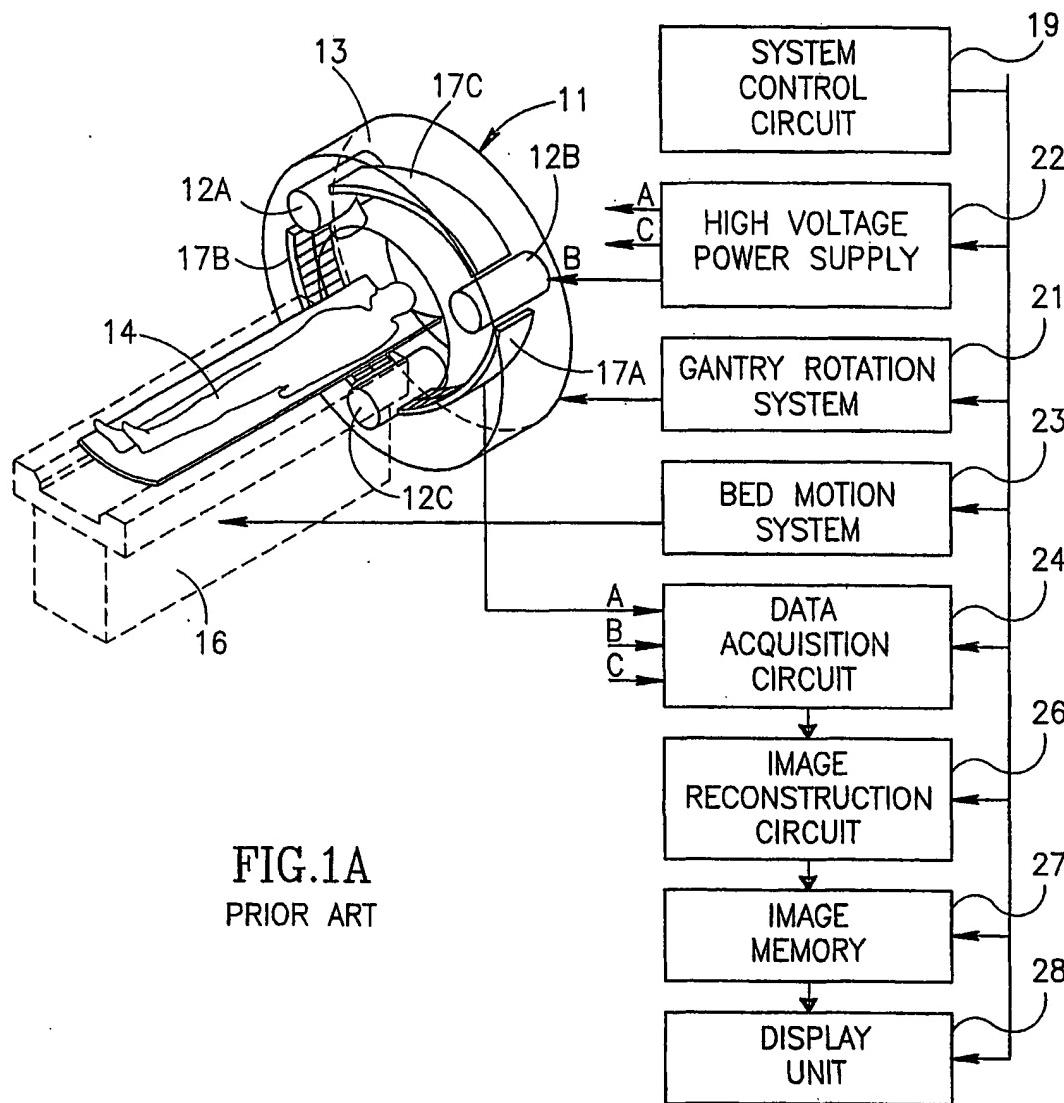


FIG.1A  
PRIOR ART

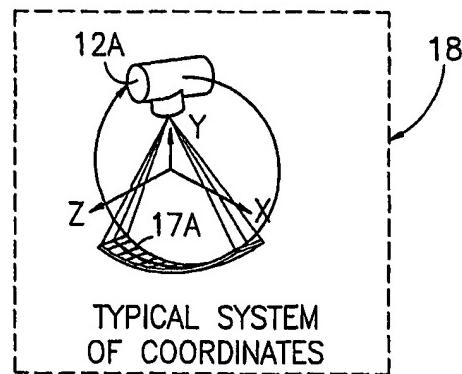


FIG.1B

2/5

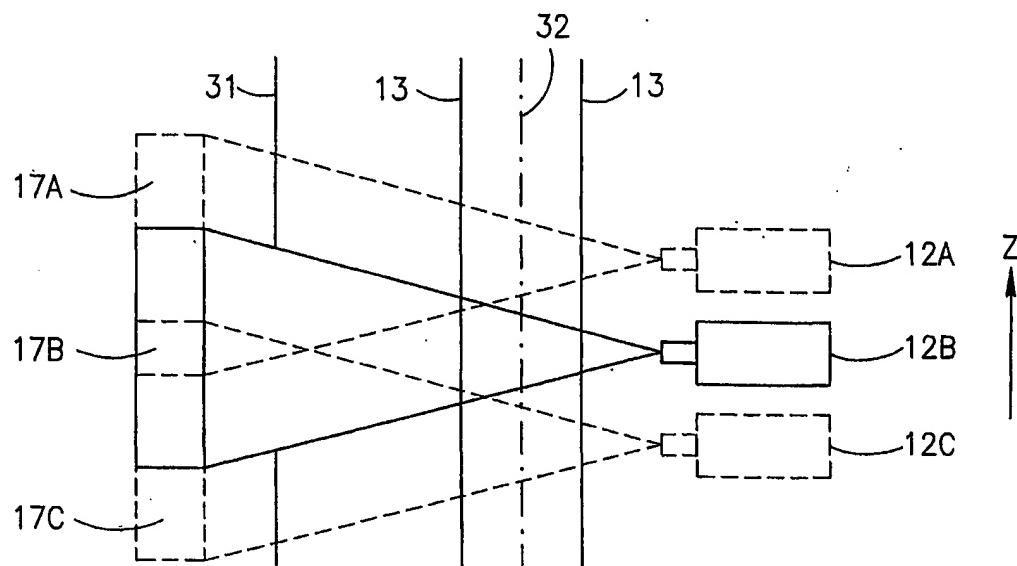


FIG.2

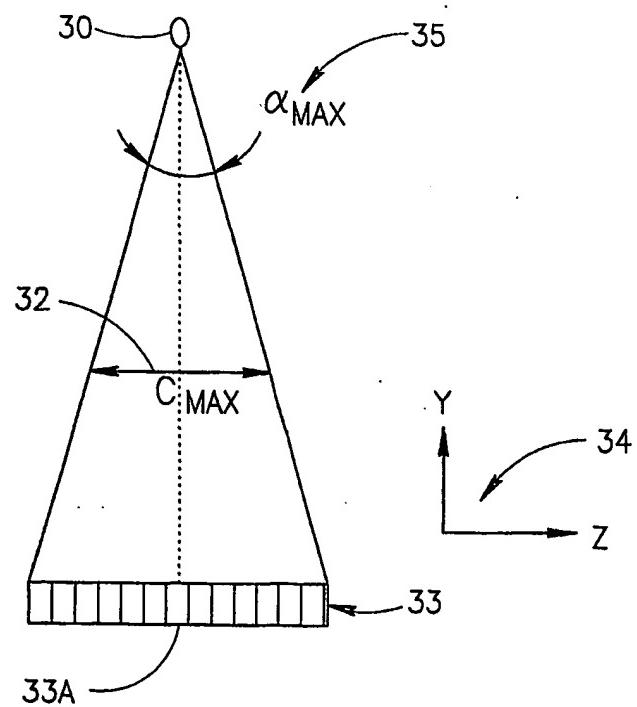


FIG.3

3/5

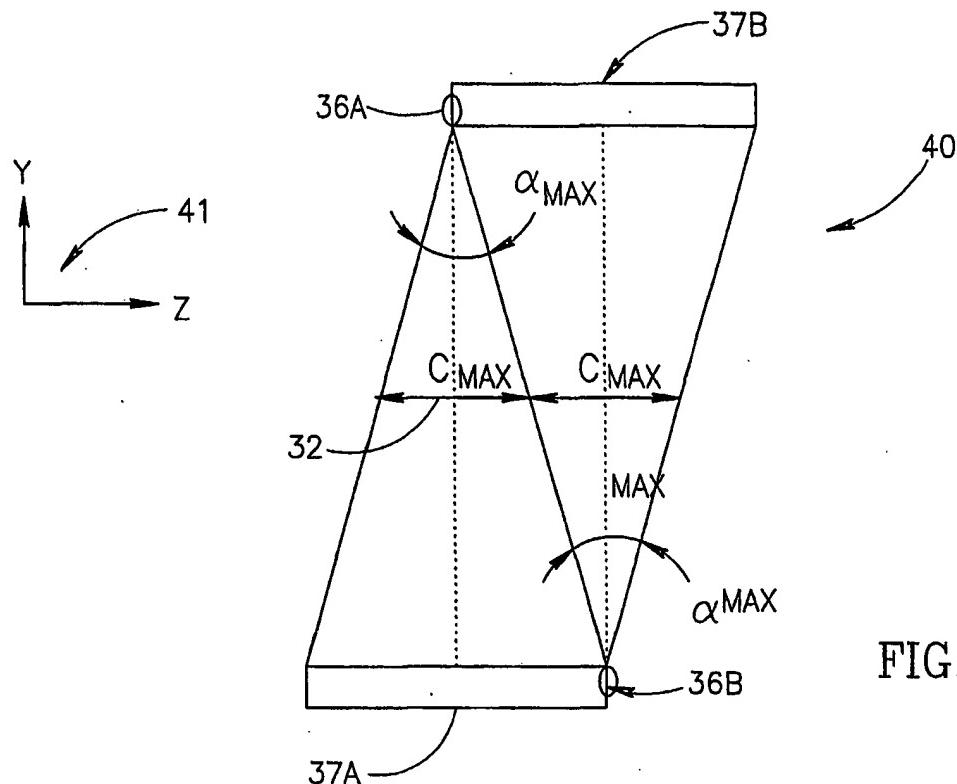


FIG. 4

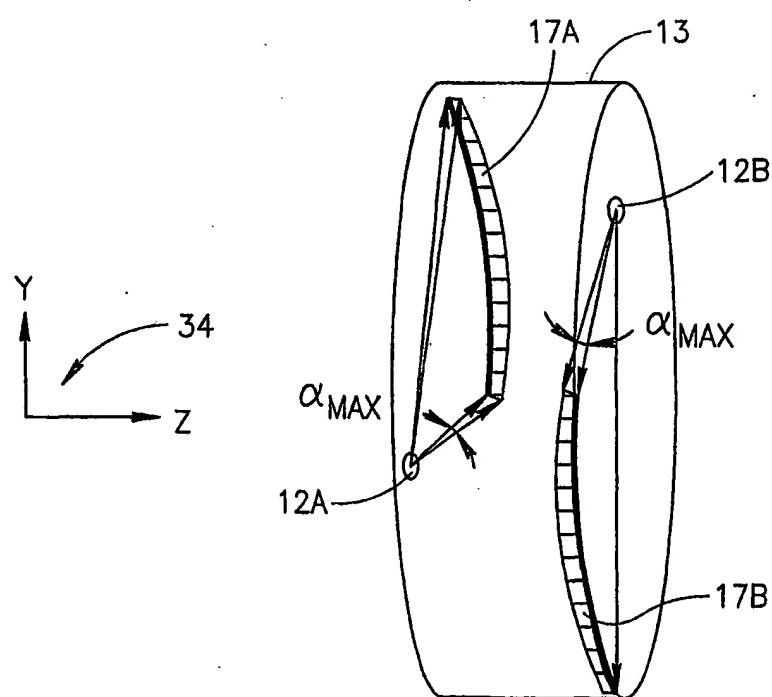


FIG. 5

4/5

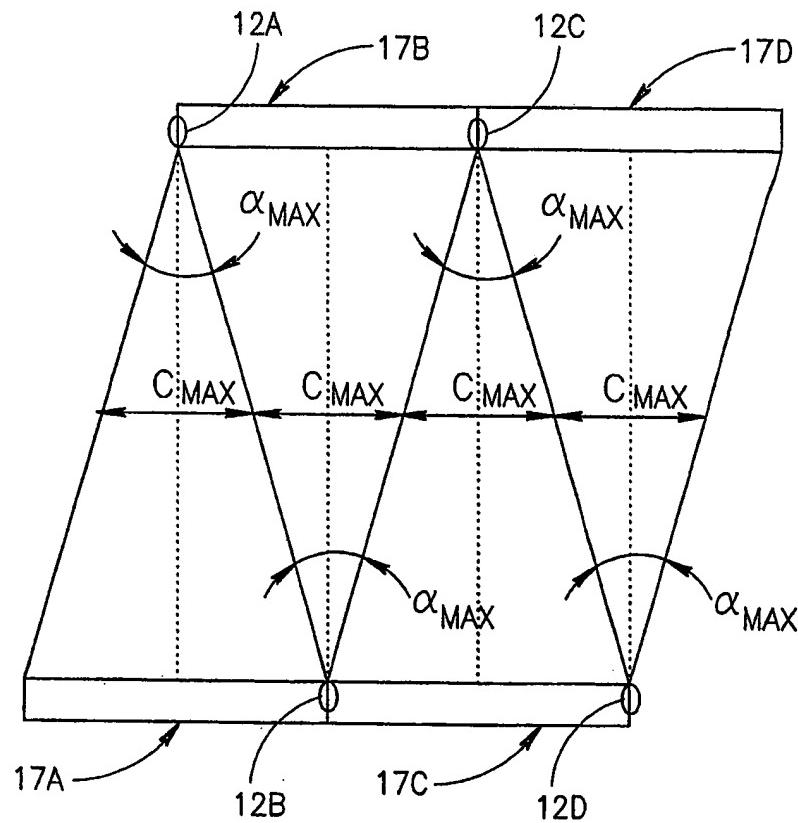
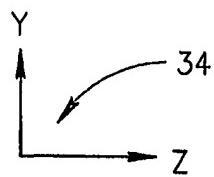


FIG.6

5/5

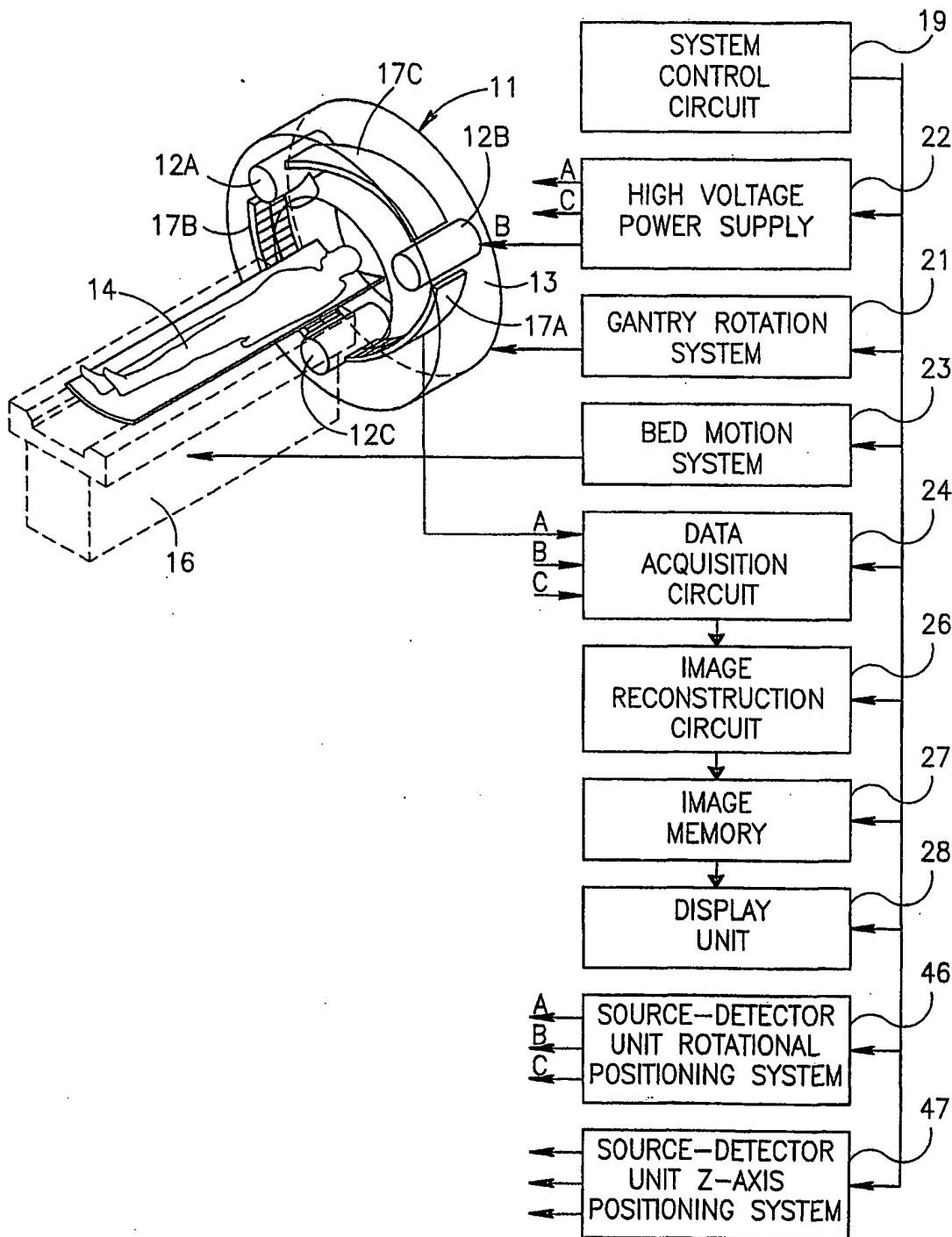


FIG.7

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 A61B6/03

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|------------|--|-----------------------|
| X          | US 4 196 352 A (BERNINGER WALTER H ET AL)<br>1 April 1980 (1980-04-01)<br>column 2, line 26-63; figures 3,5<br>column 6, line 3-24 | 1-8,<br>11-19         |
| X          | US 5 604 778 A (POLACIN ARKADIUSZ ET AL)<br>18 February 1997 (1997-02-18)  | 1-8,<br>10-19         |
| Y          | column 1, line 65 -column 3, line 23;<br>figures 1,2   | 9                     |
| Y          | US 5 625 661 A (OIKAWA SHIROU)<br>29 April 1997 (1997-04-29)<br>column 2, line 28 -column 3, line 67;<br>figures 3,4               | 9                     |

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

## \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the International filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the International filing date but later than the priority date claimed

\*T\* later document published after the International filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

\*&\* document member of the same patent family

|  |  |
|--|--|
| Date of the actual completion of the International search<br><br>22 May 2001   | Date of mailing of the International search report<br><br>29/05/2001 |
| Name and mailing address of the ISA<br><br>European Patent Office, P.B. 5818 Patenttaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | Authorized officer<br><br>Jonsson, P.O.                              |

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No  
PCT/IL 00/00610

| Patent document cited in search report | Publication date | Patent family member(s) |              |                 | Publication date                       |
|--|------------------|-------------------------|--------------|-----------------|--|
| US 4196352                             | A 01-04-1980     | DE 2916848 A            | FR 2424017 A | GB 2020138 A, B | 08-11-1979<br>23-11-1979<br>07-11-1979 |
|  |                  | JP 54152489 A           |              |                 | 30-11-1979                             |
| US 5604778                             | A 18-02-1997     | DE 4436688 A            | CN 1130498 A | JP 8299322 A    | 25-04-1996<br>11-09-1996<br>19-11-1996 |
| US 5625661                             | A 29-04-1997     | JP 7299058 A            | CN 1126578 A | DE 19515778 A   | 14-11-1995<br>17-07-1996<br>02-11-1995 |